COORDINATING RESEARCH COUNCIL, INC.
5755 NORTH POINT PARKWAY, SUITE 265
ALPHARETTA, GA 30022
TEL: 678/795-0506 FAX: 678/795-0509
WWW.CRCAO.ORG

March 29, 2019 (rev 2)
In reply, refer to:
CRC Project No. AV-27-18

Subject: CRC Request for Proposal AV-27-18, "Development of Fuel V/L Ratios for Application to System 'Suction' Capability Determination"

Dear Prospective Bidder:

The Coordinating Research Council, Inc. (CRC) invites you to submit a written proposal on "Development of Fuel V/L Ratios for Application to System 'Suction' Capability Determination"**,**" as described in the attached Statement of Work, Exhibit A.

Please indicate via letter, fax, or email by **April 12, 2019** whether or not you or your organization intends to submit a written proposal for the project. CRC will answer technical questions regarding the Request for Proposal if they are submitted in writing. CRC will then return written answers to all of the bidders, along with a copy of the original questions.

The CRC technical group composed of equipment, petroleum, and government representatives will evaluate your proposal. CRC reserves the right to accept or reject any or all proposals.

The reporting requirement will be text, data and charts to CRC in accordance with Exhibit A Statement of Work. A Final Report documenting the results of the study will be published by CRC. The reporting requirement is described in more detail in the attachment entitled, "Reports" (Exhibit B).

The "Intellectual Property Rights Clause" (Exhibit C) and "Liability Clause" (Exhibit D) will be a part of the agreement, which will be executed as a result of this Request for Proposal solicitation.

The proposal must be submitted as two separate documents. The technical approach to the problem including the proposed schedule of tasks and deliverables will be described in **Part One** and a cost breakdown that is priced by task will be described in **Part Two**. The cost proposal document should include all costs associated with conducting the proposed program.

CRC expects to negotiate either a cost reimbursable or a fixed price contract. Important selection factors to be taken into account are listed in Exhibit E. CRC evaluation procedures require the technical group to complete a thorough technical evaluation before considering costs. After developing a recommendation based on technical considerations, the costs are revealed and the recommendation is modified as needed.

Electronic copies of the technical and cost proposals should be submitted to:

Mrs. Jan Tucker
Coordinating Research Council, Inc.
5755 North Point Parkway, Suite 265
Alpharetta, GA 30022

Phone: 678-795-0506, Ext. 100
Fax: 678-795-0509
E-mail: jantucker@crcao.org

The deadline for receipt of your proposal is **April 26, 2019**.

Sincerely,

Jan Tucker
Committee Coordinator

EXHIBIT A

STATEMENT OF WORK

Project Title: Development of Fuel V/L Ratios for Application to System 'Suction' Capability Determination (AV-27-18)

Relevant Strategic Objectives & Category (near, mid, long term impact): To generate the appropriate data needed to update the SAE documents dealing with V/L and gases solubility, as well as updating CRC and ASTM publications.

Background: Currently SAE publications (References AIR1326, ARP492, ARP4024, and ARP4028) determine the ability of a fuel pump to operate when presented with a fuel and gas (i.e. V/L, vapor-to-liquid fuel ratio), or minimum required inlet pressure (fuel only): with testing performed for stabilized operating conditions and idealized test conditions, and with practices stating that testing should not be used to establish transient performance for the aircraft installation since they are not intended to establish altitude, climb rate or other transient performance of the system.

In addition, under failure conditions, there is a need for the integrated aircraft and engine fuel system to operate, when the aircraft pumps are non-operational, in a "suction" or "gravity" feed mode. Under these conditions it is critical that air evolution from the fuel does not result in a "vapor lock" condition.

Project Objectives:
Today, the CRC handbook provides limited data on air solubility for fuels, but further data is needed for both current Jet A and Jet A1 from traditional and alternative sources. CRC funding is required to support development of SAE publications for contemporary fuels by providing:

- ❑ Air solubility (and other critical properties) of various fuel types, including biofuels, to support determination of test conditions for contemporary fuels.

- ❑ Capability to estimate influence of aircraft rate of climb, and the corresponding reduction in ambient pressure experienced by the fuel, on the derived V/L ratio, enabling a more accurate mechanism to determine two phase flow conditions within the aircraft and engine fuel system during transient aircraft operation.

Project Approach:

1. **Introduction:**

A means to translate rig tests to an estimate of aircraft capability is outlined below:

- *Step 1*: For operational altitudes determine the range of fuel flows and resultant pressures experienced within the aircraft system to the fuel pump by accounting for friction pressure loss through fuel lines and head changes.

- *Step 2*: Consult SAE ARP492 Eq. A2 to determine V/L through the fuel lines and resultant expected change as fuel passes through the fuel lines to the fuel pump.

$$V/L = 1.54k\left(\frac{P_1 - P_2}{P_2 - P_{TVP}}\right)\left(\frac{t + 460}{95.8 + .07t}\right)$$

P_1 = absolute pressure at initial condition of fuel (tank), psi
P_2 = absolute pressure at new condition of fuel (pump inlet), psi
P_{TVP} = absolute TVP of fuel at test temperature, psi, step 2
t = fuel temperature at the pump inlet, °F
k = the solubility coefficient, step 3

- *Step 3*: From determining the two phase flow an iteration may be required to revise the *Step 1* derived pressures to account for flow type (e.g. homogenous flow, slug low, or stratified). Effects such as friction loss may be increased and benefits such as pressure head may be deteriorated due to stratified flow in vertical pipes. Consulting Baker two phase flow maps for horizontal pipes and vertical pipes (flow up and down) provides a means to determine flow types and revise conditions through the system to the fuel pump.
- *Step 4*: The best estimate of conditions applicable through the fuel lines and arriving at the fuel pump in terms of V/L and pressure are collated for the operational envelope.
- *Step 5*: Application of SAE publications provides an expectation for the conditions at which the fuel pump can maintain operation. Comparing to Step 4 conditions for the operational envelope enables an estimate to be made of fuel pump, and by inference aircraft, operational envelope. For flow types such as slug flow, intermittent pockets of fuel and gas are experienced and, as a result, intermittent operation of the fuel pump may be experienced and should be considered in the determination of operational envelope.

To support an estimation of aircraft operational envelope there is a reliance on the ability to determine the V/L ratio since this directly links to an estimation of:

- ❑ The two phase flow type and resultant delivery of fuel to the fuel pump to support continued operation of the fuel pump.
- ❑ The pressure conditions experienced at the pump by consideration of the impact of the two phase flow on frictional pressure losses and pressure heads.

2. **Development need:**

Recognizing the reliance on the derived V/L to understand conditions through the aircraft system to the fuel pump, confirmation of the solubility coefficient for air is required (k) for various fuel types, assuming sufficient evidence exists to support estimate of fuel vapor by accounting for true vapor pressure (P_{TVP}).

From SAE ARP492 Appendix I A.4.1, solubility coefficient, k=0.2116 x SG x (1-1.125 x SG), where SG is specific gravity of the fuel at 15°C [fuel]/15°C [water]. However this relationship was derived from JP-4 data, and it was shown not to be applicable to kerosene-type fuels. From

SAE AIR1326 Section 7.2, k can be calculated from measured air solubility (S) for a particular fuel by obtaining Ostwald Coefficient (Oc) and calculation of Bunsen Absorption Coefficient (A), where A=Oc x 492/Fuel Temp in °R (Rankine), and for fuel temperature of 32°F, S=100xA. SAE AIR1326 Table 1 (below) provides expectations for S and k.
ASTM D2779 and ASTM D3827 can also be used to determine k, but the equations developed in these test methods are empirical, and were derived from petroleum-based fuels only.

FUEL (TYPE)	S, % (Solubility Adjusted To +32 °F)	(Vol. %k mm Hg Partial Press.)
Aviation Gasoline	20-25	.026 -.033
JP-4	14-18	.0185-.024
Kerosene	12-15	.016 -.020

The k to be utilized for various fuel types is required to improve confidence in the V/L calculation and variation that may be expected. Therefore it is proposed to determine k for the below fuel types. Initially benchmarking of JP-4 will confirm the existing correlations, with consideration of other fuel types providing understanding of the variation experienced for a range of fuels commonly in use today and for the future.

- ❑ JP-4, to support bench marking ensuring consistency with existing correlations or required revisions.
- ❑ Jet A, Jet A-1. Ensure a density spread, ranging from 775 to 840 kg/m^3. Ensure that some of the fuels have no additive, and keep a record of it.
- ❑ TS-1, RT. Try to get the lowest Flash Point (FP) TS-1 or RT as possible (i.e. as close as possible to the minimum FP allowed of 28°C)
- ❑ Synthetic fuels: blends AND neats. The jet A used to make the blends needs to be analyzed as well.

Assessment of further fuel types to be performed following a review of the above fuel types' influence on V/L. The inclusion of military fuels would be beneficial to understand the effect of the additive package on the gas solubility and ultimately on V/L.

- ❑ JP-5
- ❑ JP-8
- ❑ F-24. F-24 fuel would be preferable, as it would demonstrate the impact of the additive package on the properties. Consider adding AO (antioxidant) and MDA (Metal Deactivators). The Jet A (without additives) used to make the F-24 fuel should be evaluated as well.

A further development need is required to overcome the current limitation that the V/L calculation applies for stabilized operating conditions. A reliable means of assessing aircraft transient operation is required to support an estimation of the influence of aircraft rate of climb, and the corresponding reduction in ambient pressure experienced by the fuel, leading to super saturation of fuel with air and rapid release of this previously dissolved air from the fuel. Under these situations the V/L can be greater than would be considered by application of the V/L calculation, with potential to significantly alter the two phase flow experienced and therefore conditions experienced. A further development requires a revision for the V/L calculation to enable this transient change in pressure to be recognized and enable estimate of the potential influence of aircraft operation and the potential impact various fuel types has on this transient behavior. A means to achieve this is required and this capability may be achieved by suitable consideration during the study into solubility coefficient.

Project Deliverables & Schedule:
Within 6 months, deliver data and information requested in this proposal.
The number of fuel samples considered should be enough to establish statistically meaningful correlations. For each test performed, a minimum of three (3) measurements shall be made to improve the confidence in the test results.

The two most significant properties affecting V/L and gas solubility are density and vapor pressure, but chemical composition can have a secondary effect.
For each fuel type/sample, we should test:

1) Distillation per ASTM D2887

2) Density vs. temperature per ASTM D1298 or ASTM D4052: 5°C, 15°C, 20°C, 30°C

3) Viscosity vs. temperature per ASTM D445: -40°C, -30°C, -20°C, 0°C

4) Flash Point per ASTM D56

5) True Vapor Pressure vs. temperature per ASTM D6378: 25°C, 37.8°C, 50°C, 100°C. **Additionally, another Vapor Pressure measurement per a more accurate method is also required.**

6) Solubility of gases (N_2, O_2, Air) vs. temperature[1].

   Determination of the absolute amounts of dissolved gases (nitrogen, oxygen, and argon) in hydrocarbon fuels under ambient conditions can be done using gas chromatography mass spectrometry (GC-MS) operating in selected ion monitoring (SIM) mode. After calibrating with pure hydrocarbons with known gas solubility, fuel samples are measured and the responses are compared to the standard values. The MS detector should be operated in SIM for ions with m/z of 28 (nitrogen) and 32 (oxygen). Before beginning the measurements, fuel samples and pure component standards need to be allowed to equilibrate with ambient air at the temperature considered.

[1] The sample size for GC-MS is very small, and conditioning a sample at temperatures different than ambient temperature may cause issues due to sample cooling down/warming up during fluid transfers. Selected laboratory needs to provide a detailed protocol.

Because of use of NGS (Nitrogen Generation System) on modern airplanes, another consideration should be made for an additional measurement for each sample. Saturate the fuel sample with nitrogen (by bubbling N_2 into the sample) and measure the maximum amount of pure nitrogen that can be held in the fuel sample.

Other properties may be desirable but are not critical.

Utilization of Deliverables:
Information and data collected will allow the various organizations to update the following documents:

1) SAE publications AIR1326, ARP492, ARP4024, and ARP4028.
2) ASTM D2779 "Standard Test Method for Estimation of Solubility of Gases in Petroleum Liquids" and ASTM D3827 "Standard Test Method for Estimation of Solubility of Gases in Petroleum and Other Organic Liquids".
3) CRC Handbook of Aviation Fuel Properties, mainly §2.11 "Solubility of Gases".

EXHIBIT B

REPORTS

DRAFT AND FINAL REPORT

The contractor shall distribute for the CRC an electronic pdf-compatible copy of a draft final report after completion of the technical effort specified in the contract. The draft final report shall document, in detail, the test program and all of the work performed under the contract. The report shall include tables, graphs, diagrams, curves, sketches, photographs and drawings in sufficient detail to comprehensively explain the test program and results achieved under the contract. The report shall be complete in itself and contain no reference, directly or indirectly, to the progress report(s).

The draft report must have appropriate editorial review corrections made by the contractor prior to submission to CRC to avoid obvious formatting, grammar, and spelling errors. The report should be written in a formal technical style employing a format that best communicates the work conducted, results observed, and conclusions derived. Standard practice typically calls for a CRC Title Page, Disclaimer Statement, Foreword/Preface, Table of Contents, List of Figures, List of Tables, List of Acronyms and Abbreviations, Executive Summary, Background, Approach (including a full description of all experimental materials and methods), Results, Conclusions, List of References, and Appendices as appropriate for the scope of the study. Reports submitted to CRC shall be written with a degree of skill and care customarily required by professionals engaged in the same trade and /or profession.

The CRC Steering Committee shall furnish comments regarding the draft report to the contractor within one (1) month after the draft copy.

Within thirty (30) days after receipt of the approved draft copy of the annual report, the contractor shall make the requested changes and deliver to CRC thirty (30) hardcopies including a reproducible master copy of the final report. The final report shall also be submitted as an electronic copy in a Microsoft WORD and a pdf or pdf-convertible file format. The electronic copy will be made available for distribution by CRC.

EXHIBIT C

INTELLECTUAL PROPERTY RIGHTS

Title to all inventions, improvements, and data, hereinafter, collectively referred to as ("Inventions"), whether or not patentable, resulting from the performance of work under this Agreement shall be assigned to CRC. Contractor X shall promptly disclose to CRC any Invention which is made or conceived by Contractor X, its employees, agents, or representatives, either alone or jointly with others, during the term of this agreement, which result from the performance of work under this agreement, or are a result of confidential information provided to Contractor X by CRC or its Participants. Contractor X agrees to assign to CRC the entire right, title, and interest in and to any and all such Inventions, and to execute and cause its employees or representatives to execute such documents as may be required to file applications and to obtain patents covering such Inventions in CRC's name or in the name of CRC's Participants or nominees. At CRC's expense, Contractor X shall provide reasonable assistance to CRC or its designee in obtaining patents on such Inventions.

EXHIBIT D

LIABILITY

It is agreed and understood that ____________ is acting as an independent contractor in the performance of any and all work hereunder and, as such, has control over the performance of such work. ______________ agrees to indemnify and defend CRC from and against any and all liabilities, claims, and expenses incident thereto (including, for example, reasonable attorneys' fees) which CRC may hereafter incur, become responsible for or pay out as a result of death or bodily injury to any person or destruction or damage to any property, caused, in whole or in part, by _________'s performance of, or failure to perform, the work hereunder or any other act of omission of Contractor in connection therewith.

EXHIBIT E

PROPOSAL EVALUATION CRITERIA

1) Merits of proposed technical approach (Part One).

2) Previous performance on related research studies (Part One).

3) Personnel available for proposed study – related experience (Part One).

4) Timeliness of study completion (Part One).

5) Cost (Part Two).